

DOCUMENT RESUME

ED 295 623

IR 013 333

AUTHOR Aust, Ronald
TITLE Constructing Mental Representations of Complex Three-Dimensional Objects.
PUB DATE Jan 88
NOTE 21p.; In: Proceedings of Selected Research Papers presented at the Annual Meeting of the Association for Educational Communications and Technology (New Orleans, LA, January 14-19, 1988). For the complete proceedings, see IR 013 331.
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cognitive Style; Comparative Analysis; Computer Graphics; Higher Education; Instructional Design; Microcomputers; *Perception Tests; *Sex Differences; *Spatial Ability; *Visual Perception; Young Adults
IDENTIFIERS Dimensional Analysis; *Mental Representation

ABSTRACT

This exploratory study investigated whether there are differences between males and females in the strategies used to construct mental representations from three-dimensional objects in a dimensional travel display. A Silicon Graphics IRIS computer was used to create the travel displays and mathematical models were created for each of the objects using computer graphics. These graphics were edited and transferred to videotape and a hypercard program was created to complement the orientation phase of the videotape. The subjects were asked to identify the correct object from the alternatives presented on the computer monitor as soon as the three-dimensional objects had passed through a two-dimensional plane described as "the detector field"; each subject was individually tested by an observer. The t-test procedure found in the Statistical Process System software package was used to compare the abilities of male and female subjects to identify the objects correctly at each of five levels of difficulty. Although other studies have found males to perform better than females on many tests of visual/spatial ability, a difference is not evident in this study. These conclusions are tentative, however, because of the size and unbalanced nature of the sample of 10 males and 31 females. The text is supplemented by four figures and one table. (31 references) (EW)

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Constructing Mental Representations of Complex Three-Dimensional Objects

Ronald Aust
University of Kansas

Instructional Technology Center
Bailey Annex
University of Kansas
Lawrence, Kansas 66045
(913) 864-3057

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Ronald Aust
University of Kansas

With the advent of the information processing paradigm, researchers interested in human learning often consider how strategies used in programming computers are analogous to certain mental functions. Drawing on this computer metaphor, scientists at MIT's media lab, including Alan Kay and Seymour Papert, are designing instructional strategies for using computers to expand mental functions and cognitive flexibility (Brand, 1987). Instructional approaches supported by Kay and Papert focus on the development of parallel mental processes used to recognize patterns and construct relationships in the visual mode. The progress that the MIT group has made, with the computer-enriched environment at the Hennigan grade school in Boston, indicates that this "right brain" approach to instruction may offer a viable alternative to the more linear approaches used in traditional language-driven instruction.

Many of the strategies for using computer graphics to develop constructive mental processes focus on the acquisition of cognitive abilities by depicting stages of a concept or event in an iconic or pictorial format. The icons used in this type of instruction attempt to replicate what the objects or events would look like from the natural perspective while the relationships between the concepts are depicted as consequence rather than process. Thus, the learners are left with the task of comprehending abstract relationships which may not fit into their cognitive schemata.

An alternative approach is to identify valid cognitive processes and design displays which elicit affiliated perceptual processes through tasks which require mediation of relationships which resemble those involved in the targeted cognitive process. Once elicited, these perceptual processes might be used to facilitate transfer to the targeted cognitive processes.

Psychobiographies of noted intellectuals (Shepard, 1978; Hadamard, 1945) suggest that the ability to mentally construct images which possess three-dimensional properties can contribute to creative thinking. For example, in describing the thought processes he used in developing "The Special Theory of Relativity," Einstein explained that he mentally constructed images of various objects while imagining he was traveling at the speed of light. When what he observed did not coincide with existing theory, he was left with the task of systematically converting what he had "seen" into mathematical expressions. Thus, the ingenuity of Einstein's discovery was more dependent on his ability to form abstract mental representations of an idealized world than on his expertise in mathematics.

Einstein's imaging ability could not have been based entirely on environmental equivalents, because no such equivalents exist. Instead, it required a novel construction of mental representations on the basis of anticipated changes in spatiotemporal information. Mediated displays, which require the learner to employ such processes at the perceptual level, might facilitate the development of these spatiotemporal processes and thereby contribute to creative thinking. This study focuses on the nature of the processes involved in forming mental representations from different methods of depicting complex three-dimensional objects on two-dimensional surfaces.

Media techniques for representing the interior of objects, on the limited two-dimensional surfaces of a sheet of paper or video screen, have primarily been based on the perception principles we use to identify objects in the real world. By combining orthographic projection with surface renderings, color and shadowing techniques, artists can depict the exterior of objects as transparent; thereby revealing various interior sub-components. With the addition of computer animation, these three-dimensional depictions become more convincing when the objects are shown as rotating in space. However, even when computer animation is used, surface based depictions can not adequately represent all the interior components of more complex objects such as the brain or the geological structure of the earth.

A commonly used technique for depicting the interiors of more complex objects is to present the object as a sequence of cross-sections or slices. In neuroanatomy, brain slices are individually stained and converted to diagrams which are presented in succession on the pages of an atlas. The atlas technique requires that each diagram have a separate orienting procedure indicating the slicing axis and the location or depth from which the cross-section was taken. While some learners are capable of using the atlas technique to construct meaningful images, many others learners have difficulty integrating the procedures for mentally combining the individual cross-sections. A technique which uses computer graphics to display the cross-sections in continuous succession may provide a more effective means for developing abilities to form mental representations of three-dimensional objects with complex interiors.

The processes under investigation are those which influence the construction of mental representations from a sequence of cross-sections depicting a three-dimensional object traveling in a continuous path through a two-dimensional plane (see Figure 1). The viewer of this dimensional travel display must therefore construct a mental representation, which possesses three-dimensional properties, on the basis of changes which occur in two dimensions over time. Unlike the atlas technique, the dimensional travel technique provides the opportunity of constructing the three-dimensional mental representation directly from the stimuli. The perceiver can act on the incoming information immediately without relying later on strategies for reconstructing a three-dimensional image from a series of memorial representations. Thus, although the processes involved in dimensional travel may resemble cognitive imagery processes, they are considered perceptual.

Generalizing Dimensional Travel to Affiliated Cognitive Processes

According to supporters of central theories of perception (Fleming, 1987; Rock, 1983; Norberg, 1978; Gregory, 1977), individuals actively construct percepts from several sources of information including the information available in the external world, internal feedback and previous experience. Central theories assume that there is a reciprocal interaction between perception and cognition. As new information is acquired it alters the structure of internal cognitive schemata which in turn influences the way new information is analyzed. Norberg (1966, 1978) and Salomon (1981) have argued that central theories are more viable guides for instructional research because they assume perception is a constructive process that can be controlled by the viewer and not just a direct apprehension of some pre-existent reality.

In addition to providing a new means of conceptualizing the interior of complex objects, the processes acquired during the viewing of the dimensional travel displays may serve to elicit cognitive imagery skills. Piaget and Inhelder, contended that perceptual observations serve as precursors to higher order cognitive processes. For example, Piaget (1966a) claimed that a child's ability to anticipate the height that a given amount of liquid will reach when poured from a narrow to a wide glass (anticipatory imagery) is in part dependent on the child having observed similar transformations of liquids in the natural world. This ability to mentally manipulate perceptual-like or analog mental images has also been linked to development of memory (Paivio, 1976; Bower, 1972), reasoning skills (Kaufmann 1979; Piaget & Inhelder, 1971; Bruner, Olver & Greenfield 1966) and creative thinking (Finke, 1980; Shepard 1978; Hadamard, 1945).

Potential Difficulties in Solving the Dimensional Travel Task

This study is exploratory. It is designed to investigate some of the strategies which different learners use in constructing mental representations from the dimensional travel display. The shape and complexity of both the objects displayed and the distractors selected for the forced-choice alternatives have been designed to reveal difficulties which learners may have in forming mental representations of various types of objects presented with the dimensional travel display.

The participants in this study see two different techniques for depicting three-dimensional objects on a two-dimensional surface. One method is the dimensional travel display which is a dynamic depiction of the surfaces of the objects and their interior components. The second method is the traditional orthographic procedure using perspective, hidden lines, surface transparency and shadowing to depict the objects and their interior components in a static mode. (Figure 2 shows the static displays of the forced-choice alternatives used for the dimensional travel display depicted in Figure 1). Thus, the recognition task requires the subject to first construct a mental representation of the three-

dimensional object based on observing the dimensional travel display, store the mental representation in memory and then decode it in order to identify the correct option from the orthographic projections of the forced-choice alternatives.

Studies of anorthoscopic (abnormally viewed) perception (Aust, 1984; Rock, 1983) have found that simple and familiar figures are more easily recognized than complex and unfamiliar figures. Anorthoscopic perception refers to the ability to recognize figures as they pass behind a narrow stationary slit. Recognition of anorthoscopically presented figures can be considered as a problem of recovering a two-dimensional figure from the motion information which takes place along a one-dimensional slit. The assumption is that the familiar figures assist the viewer in establishing hypothesis for constructing the mental representations. Thus, when objects are presented with the dimensional travel technique, the simple objects should be more easily recognized than the complex objects. However, there is no evidence which indicates which aspects of object complexity present the most difficulty in mediating a dimensional travel display.

The shapes depicted in this study were all regular three-dimensional translucent solids: spheres, pyramids, cubes, cylinders, rectangular solids and a rotated rectangular solid described as a diamond. The complexity of the objects was based on the number of internal solids that the objects contained, the degree of embeddedness and the shape of the solids. Five levels of object complexity were identified. The simplest level, coded O-O, was a medium sized solid embedded in the center of a larger solid. The next level of difficulty, coded O-O/O, was two adjacent medium sized solids both embedded in a larger solid. The third level, coded O-O-O, was a small solid embedded in the center of a medium sized solid which was embedded in the center of a still larger solid. The fourth level, coded O-O/O-O, was a small solid embedded in a medium solid which was adjacent to another medium sized solid, all of which were embedded in a larger solid.

The most difficult level of object complexity, coded O-C/D, was based primarily on shape differences (see Figure 3). All of the objects in this level were embedded in the center of a rectangular solid. The internal solids in these objects were cylinders and the diamond solids. The diamonds were actually rectangular solids which were rotated so that the facing surfaces were 90 degrees from the facing surfaces of the larger rectangular solid. The interior solids were all the same length and height with a horizontal length equivalent to the horizontal length of the larger rectangular solid. They were oriented so that their horizontal center lines were parallel to the facing square of the larger rectangular solid in which they were embedded. Thus, the horizontal center line of the cylinder was parallel to the slicing plane. In this orientation, the cross-sections of the diamond solids are very similar to the cross-sections of the cylinders. The primary difference relates to the relative depth of the cross-sections.

When the cylinder first appears in the display, the cross sectional view shows a somewhat wider band than the diamond shaped object. This is because a greater portion of the cylinder's surface is tangent to the slicing plane. If the cross-sections produced by the diamond solid and cylinder are compared as they move through the slicing plane, the height of the respective rectangles increase at a different rate. When the diamond solid passes through the slicing plane, the resulting rectangle increases at a constant until it reaches the maximum height and then decreases at a constant rate until the solid has passed through the slicing plane. When the cylinder passes through the slicing plane, the change in the rectangle's height is initially rapid. The change slows down as the maximum diameter is reached and finally increases again before the cylinder passes completely through the slicing plane.

The differences between the way the cylinder and diamond shape appear as they pass through the dimensional travel display are subtle. However, they are crucial to understanding the spatiotemporal processes required in mediating the display and may reveal a preference for either the spatial or temporal component. Learners who have difficulty identifying the difference between the two displays may have similar problems in recognizing sequential differences in an atlas of the brain or cross-sections of geological structures. Deficiencies in mediating these spatiotemporal differences might serve as guides for redesigning presentation strategies which begin with the obvious and progressively move to more subtle distinctions.

Mental Representations Formed in Solving the Dimensional Travel Task

Studies of the ability to mentally rotate figures (Shepard & Metzler, 1971) have found that the time it takes to recognize a rotated figure is an analog of the number of degrees the figure has been rotated. These studies provide evidence that the subjects were mentally rotating visual images of the figures. Other evidence for the construction of visual mental representations has been found in studies of anorthoscopic perception (Aust, 1984; Rock, 1983). When a target is introduced in an anorthoscopic display to indicate the speed at which a figure is moving behind a slit while the actual figure speed remains constant, the length of the perceived figure increases with each decrease in the target's speed and decreases with each increase in the target's speed. Thus, the nature of the constructed percept, which many subjects reported "seeing," was influenced by the both spatial components as revealed through the slit and the temporal components indicated by the speed of the moving target.

The dimensional travel task is in some ways similar to both the mental rotation and the anorthoscopic perception tasks. The orienting processes used to determine the axis of the object in relation to the slicing plane are similar to the orienting processes required in the mental rotation task; while the ability to mentally construct dimensional properties on the basis of a sequence of slices is similar to the anorthoscopic perception

task. If subjects who view the dimensional travel display report that they see faint copies of the three-dimensional objects, this would indicate that they immediately formed a perceptual-like mental representation. If, on the other hand, they report using a verbal mnemonic strategy, some level of propositional coding would be indicated.

Another way of investigating the nature of the mental representations, formed while viewing the dimensional travel display, is to look at what type of errors are made. Subjects who rely on a verbal coding strategy for remembering the internal components of the objects may be more likely to make errors in the embeddedness or order of the object's sub-components. This is because they must first decode the icons from the dimensional travel display into a verbal mnemonic (e.g. square inside triangle inside circle), remember the verbal sequence and then decode the verbal sequence in identifying the correct orthographic projection. On the other hand, subjects who rely on a visual/holistic encoding strategy would be less likely to make an order error because such errors usually represent a radical change in the visual structure of the object.

For example, if the object presented in the dimensional travel display is the option which appears at the top center of Figure 4, the option at the bottom center is one of the order errors (both object are made up of a cube, two pyramids and a sphere). A viewer who uses a verbal code to remember the sequence of objects components and then rearranges the sequence during storage or recall, might consider this a viable alternative. However, if the viewer relies entirely on a visual/holistic strategy for storage and recall, this order error seems much less viable because the visual structure is radically different from the correct option. The visual/holistic viewer's errors are more likely to be represented by the position error at the top right of Figure 4 which is a rotation of the correct option.

Sex Differences in Visual-Spatial Abilities

The assumption that males perform better than females on some tests of visual spatial ability has been supported by several researchers (Conner & Serbin, 1977, 1985; Lohman, 1986; Maccoby & Jacklin, 1974; McGee, 1979). Some investigators (Maccoby, 1966; Maccoby and Jacklin 1974) have found that the most marked differences in spatial visualization appear after the onset of puberty. These studies suggest that differences in spatial ability may be, at least in part, attributable to biological gender differences. Others (Conner & Serbin, 1985; Gagnon, 1985), have found that training in visual-spatial skills benefits females more than males which suggests social or environmental factors. Research which focuses on specific visual-spatial abilities, such as those required in mediating the dimensional travel display, may yield strategies to accommodate for sex differences or adjust possible sex bias in instructional procedures.

METHOD

Subjects

Student volunteers were 10 males and 31 females (mean age of 24.1) who were enrolled in education classes at the University of Kansas.

The Dimensional Travel Display

A Silicon Graphics IRIS computer was used to create the dimensional travel displays of the three-dimensional objects. Mathematical models were created for each of the objects using the graphics tools which are part of the IRIS system software. The objects and sub-components were rendered as shells with white surfaces. A blue opaque plane was positioned so that its axis was parallel to the front of the monitor's screen. When an object was presented in the dimensional travel display it was initially positioned behind the opaque field. The object was then directed along the Z axis so that, as it passed through the slicing plane, the outline of the object's surfaces appeared as thin lines. The result was a dynamic depiction of a white three-dimensional object passing through a blue field. The monitors in Figure 1 accurately depict proportions.

A meter, designed to indicate the depth of the object in the slicing plane, was positioned at the bottom of the screen. As an object passed through the slicing plane a red bar moved along the meter indicating the object's depth along the Z axis.

Once the graphics had been created on the IRIS system they were transferred to videotape using a Silicon Graphics genlock board and a Lenco sync generator/encoder. The videotape, which was edited for testing, began with an orientation segment showing a wire frame three-dimensional object passing through a two-dimensional field while the function of the meter was demonstrated. The orientation segment concluded with a sample item which was representative of the dimensional travel objects presented during the testing phase.

The testing phase of the videotape consisted of dimensional travel displays of 30 objects (5 difficulty levels X 6 objects). Each dimensional travel display was preceded by a 3 second warning that the "Object is Arriving," and concluded with a 5 second countdown during which the words "Identify Object" appeared on the screen.

The Forced-Choice Alternatives

Orthographic projections of the objects presented in the dimensional travel display and the alternative objects were created using Super Paint software on an Apple Macintosh II computer. Shadowing techniques, hidden lines, and surface transparency were used to create convincing depictions of the three-dimensional objects. The object renderings were then incorporated in a Hypercard program.

The Hypercard program began with a segment which complemented the orientation phase of the videotape. A scenario describing how the objects had been lost in space and needed to be recovered was created in order to assist the subjects in developing the hypothesis that three-dimensional objects would pass through a two dimensional plane described as "the detector field." The scenario explained that it was their task to identify the correct object from amongst the alternative which would be presented on the computer monitor as soon as the object had passed through the detector field.

Each of the response screens included six forced-choice alternatives - one correct response and five distractors. The distractors were selected to represent three different types of errors: shape, position and order. Shape errors were ones in which at least one of the solids which composed the objects was of a different shape from any of the solids depicted in the corresponding dimensional travel display of the object. Position errors were ones in which all solids were of the same shape but the position of the internal solids was reversed. Order errors were when the level of embeddedness and size of the solids was reversed but the shape and number of the solids was the same. The distractors were counterbalanced so that there was an equal number of shape, position and order errors (50 each) for the thirty objects.

Procedures

Each subject was individually tested by either a male or female observer. The videotape was presented on a 13" video monitor which was located to the right of and directly adjacent to the computer monitor. The observer prepared the videotape and Hypercard program and led the subject through the orientation phase. A question and answer period was provided both before and after the subject saw the sample item. When the subject agreed that the task was understood, testing began.

During testing the computer monitor showed a "Wait to Identify Object" screen while the video monitor depicted the first dimensional travel object. As soon as the object had passed through the detector field on the video monitor the observer advanced the computer program to display the forced-choice alternatives. The subject was allowed five seconds to select one of the six objects which appeared on the computer screen. The observer positioned the pointer on the subject's selection and pressed the mouse which automatically recorded the subject's response and advanced the program to the next "Wait to Identify Object" screen. This procedure was repeated for the remaining 29 objects.

An informal question and answer discussion followed the collection of quantitative data. The subject were asked questions such as: "How did you remember which object had passed through the detector field? Did you actually see the object as it passed through the detector field? Did you use the meter to help you see the object? Explain what you saw when you watched the objects pass through the detector field."

Analysis

The T-Test procedure found in the SPSS software package was used to compare the ability of males and females to correctly identify the objects at each difficulty level. A summary of the means appears in Table 1. Differences were not significant at any of the difficulty levels. A review of the means indicates that, at least at this adult age, females may have no more difficulty than males in identifying the objects presented with the dimensional travel display.

Because the alternatives used for each of the object levels were different, tests of significance were not used to compare the error types or object difficulty levels. References to means are used as general indicators of performance. The mean number of correct responses for all object levels ($M = 4.67$ out of 6 possible) indicated that the subjects were capable of recognizing many of the objects presented with the dimensional travel display. There was a possible tendency to make shape errors ($M = .86$) over order ($M = .24$) or position ($M = .22$) errors. However, this trend was primarily a reflection of the responses to difficulty level five objects. When the errors made on the first four object difficulty levels are compared, the small difference between the mean shape ($M = .03$), order ($M = .18$) and position ($M = .27$) errors did not suggest a tendency.

The means in Table 1 provide a general indication that as the previously identified object difficulty level increased, the ability to recognize the correct object decreased. The most marked decrease in ability to correctly identify the object occurred at difficulty level five. The level five objects were the ones in which the subjects had to differentiate between the cylinder and the diamond shape solids. At level five, the subjects selected more of the shape distractors ($M = 4.20$) than they did the correct responses ($M = 1.25$). This result could reflect random guessing because there were four shape distractors for each item at this difficulty level.

The mean number of correct responses for the first four difficulty levels was 5.52 out of the 6 possible for each category. This indicates that adult learners were able to recognize most of the objects presented with the dimensional travel display when the shape of the interior solids was sufficiently different so as not to require extensive reliance on the temporal component. That is, when the object could be differentiated from the alternatives on the basis of remembering the outlines in a few representative slices, the subjects were more likely to identify the correct alternative. Whereas, when the orientation and shape of the components within the objects produced dimensional travel displays which differed primarily by the rate at which the outlines were revealed, the subjects were less likely to identify the correct object.

The assumption that the subjects relied more heavily on the spatial component than on the temporal component was also evident in their descriptions of how they solved the task. Out the 41 participants, 26 specifically reported using internal verbalization strategies for remembering the structure of the objects. A typical comment was, "I remembered the shapes from left to right. I would say circle, triangle, square or whatever and then I would look for them in the shapes on the computer." Other subjects reported a similar verbal strategy except that they remembered the objects from the outside to the inside. When these subjects were then asked to explain how they remembered the position of the shapes they would typically say they also internally verbalized the shapes from left to right. The subjects who relied on internal verbalization rarely reported using the meter for anything more than to tell when the object was about to leave the detector field.

A few of the subjects reported using psychomotor representations of the objects' components. One of these subjects explained, "When I saw a circle on the outside I would make a circle with my first two fingers and then the next shape with my next finger ... I put the shapes on the left in my left hand and the shapes on the right in my right hand." One subject reported using a combination of internal verbalization and psychomotor representation. She explained that she would say the shapes to herself and then tilt her head in the direction of the shapes.

Only 7 of the 41 subjects specifically reported forming iconic images of the objects while viewing the dimensional travel display. These subject typically said they made a picture of the object in their mind and then looked for the picture on the computer screen.

One girl, who responded correctly to all of the options, explained, "After I saw the first one (the sample), I decided to make a picture of the shapes in my mind. I'm good at that kind of thing but I'm glad the first ones were easy because it took awhile for me to get the hang of it....The ones with the cylinders and stuff were the hardest but after I got it, I could just see the detector field go around the edges." When asked if she used the meter in any way she replied, "Well I didn't watch it directly but I think I was using it subconsciously... I'm glad it was there. I think it helped me see the objects."

Discussion and Recommendations

Because advances in microcomputer technology have only recently made this method of presenting three-dimensional objects practical in instructional settings, there were no existing guidelines for using the dimensional travel technique to depict complex objects or enhance abstract visualization skills. Nor was there evidence to indicate which type of learners would have success or difficulty in mediating the dimensional travel display.

Other studies have found that males perform better than females on many tests of visual/spatial ability. The difference between males and females was not evident in this study. Perhaps the spatiotemporal skills required in mediating this type of display are sufficiently different from the skills required for the static tests commonly used to assess visual processing. Another possibility is that proficiency in internal verbalization, which many of the subjects reported using, may have offset any deficiency in encoding or decoding the visual components. However, these conclusions are tentative because of the limited sample size and similar research using larger sample sizes, which are balanced for males and females, is recommended.

Differences in ability to mediate the dimensional travel display may also occur at different developmental levels. Several researchers (Cooper & Shepard, 1973; Piaget & Inhelder, 1971; Rohwer, 1970; Shepard & Podgorny, 1978), have contended that the ability to construct and transform mental representations increases with age. A previous study (Aust, 1984), which addressed spatiotemporal processes similar to those required for the dimensional travel task, found that anorthoscopic perception followed a developmental trend. Findings from this study, especially those which relate to the selection of objects and orientation of the slicing plane, will be used to refine the procedures in making the display appropriate for a younger population. Further studies with a younger population could lead to a developmental approach for training in spatiotemporal processing ability.

The most difficult aspect of mediating a dimensional travel displays involves the analysis of the temporal component. If the goal is to explicitly reveal the interior components of complex three-dimensional objects to the broadest range of learners, the primary factor in determining the orientation of the slicing plane should be based on differences in the shapes revealed as opposed to differences in the temporal component or rate of revelation. For example, the cylinder and diamond solids would have probably been recognized by a broader range of subjects if the objects had been rotated 90 degrees along the horizontal axis so that the slicing plane reveals a circle and diamond. Another procedure, which is presently used with some medical technologies such as MRI or CAT scans, is to reveal the same three-dimensional object using several different slicing orientations.

However, a different set of recommendations are in order if the instructional goals extend beyond simply revealing the interior of objects to the development of abstract reasoning skills in spatiotemporal processing. One instructional strategy might begin with displays of objects which focus primarily on the spatial component and gradually move to displays which require more temporal analysis. This strategy could be augmented by moving from exercises, in which the alternatives are presented while the object is being revealed, to exercises which require the student to remember what has been displayed before seeing the alternatives.

The students could also be asked to generate drawings of the objects presented in the dimensional travel display, either with paper and pencil or with computer drawing programs. Another possibility is to provide three-dimensional transparent objects and have students make a sequence of drawings to represent what the object would look like as it travels through the detector field.

One of the outcomes of the computer revolution has been to make us aware of the complexity and intellectual sophistication of our perceptual abilities. Computer scientists have created machines capable of remarkable feats in storing, retrieving and manipulating both graphic and verbal/mathematical information. However, despite numerous challenges, they have been unable to create a computer capable of reliably differentiating a dog from a cat (Brand, 1987). Could this mean that the seed of human ingenuity is rooted more deeply in our perceptual abilities than we have previously recognized?

Paper based instructional support materials have led to a reliance on verbal/mathematical systems for teaching reasoning skills - possibly because it was less expensive and faster to present ideas in words and numbers than it was to produce pictures, icons or animated depictions. As we move from paper based to electronic based instructional support materials, students will be able to access a greater variety and amount of information in much less time than they have in the past. However, they will not be adequately prepared to enter the third wave information society by simply applying a linear approach in consuming more and more information. They must be able to select relevant information, see novel relationships between diverse concepts and invent new strategies for combining a variety of information forms in constructing meaningful wholes.

Continued research, which yields insights into the way we construct meaning at the perceptual level, will assist in developing sound foundation for addressing these abstract reasoning skills. A more comprehensive plan for enhancing perceptual abilities may result from this research. But teachers can begin now by recognizing the importance of perceptual abilities while selecting materials and developing activities which encourage students to discover original ways to perceive their world.

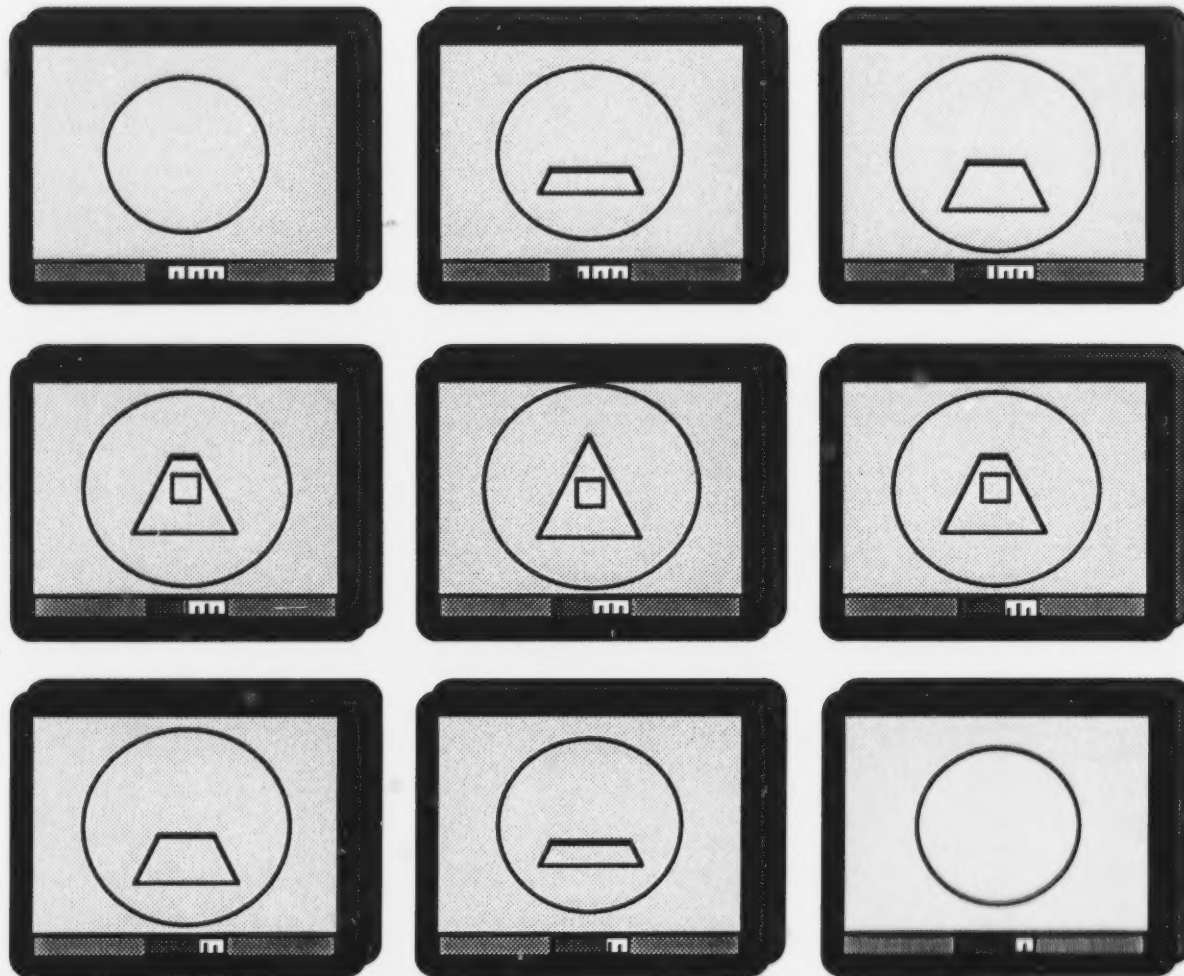
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Figure 1
Dimensional Travel Display of a
Cube Inside a Pyramid Inside a Sphere



The above figures show one of the thirty object as it travels through the dectector field. The meter at the bottom of each screen indicates the distance that the object has passsing through the screen. In this case the three-dimensional object which is passsing through the screen is a cube inside a pyramid inside a sphere.

Figure 2

The Forced-Choice Alternatives for the
Dimensional Travel Display Depicted in Figure 1

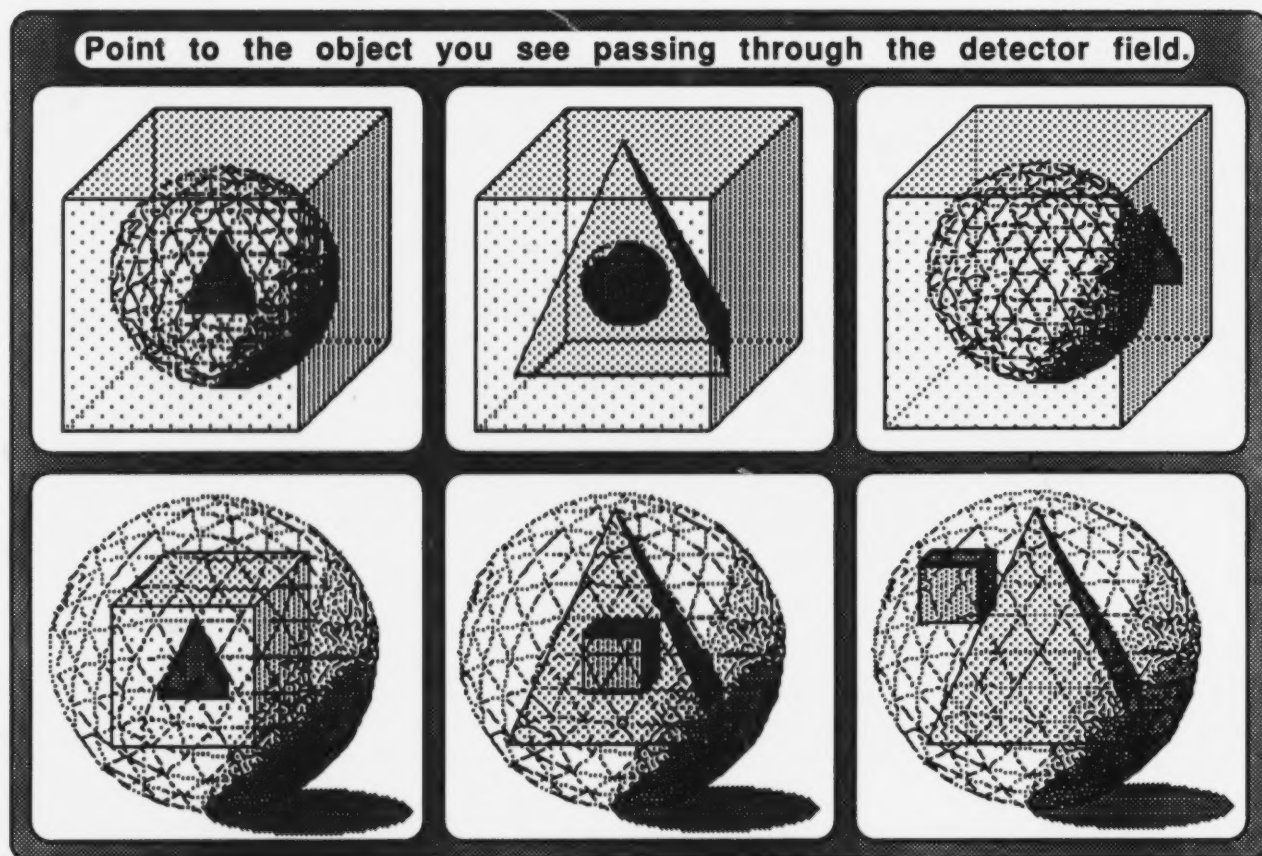


Figure 3

The Forced-Choice Alternatives for the
Level Five Objects

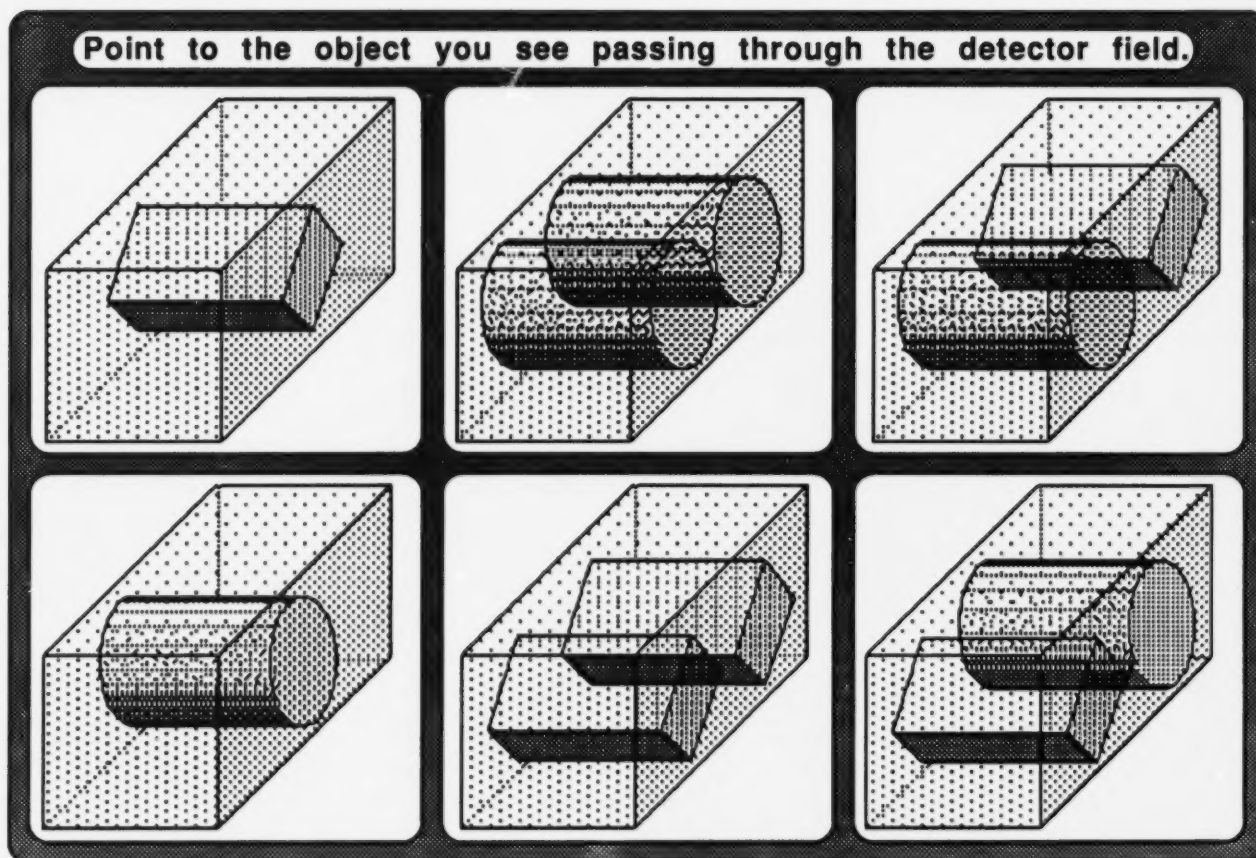
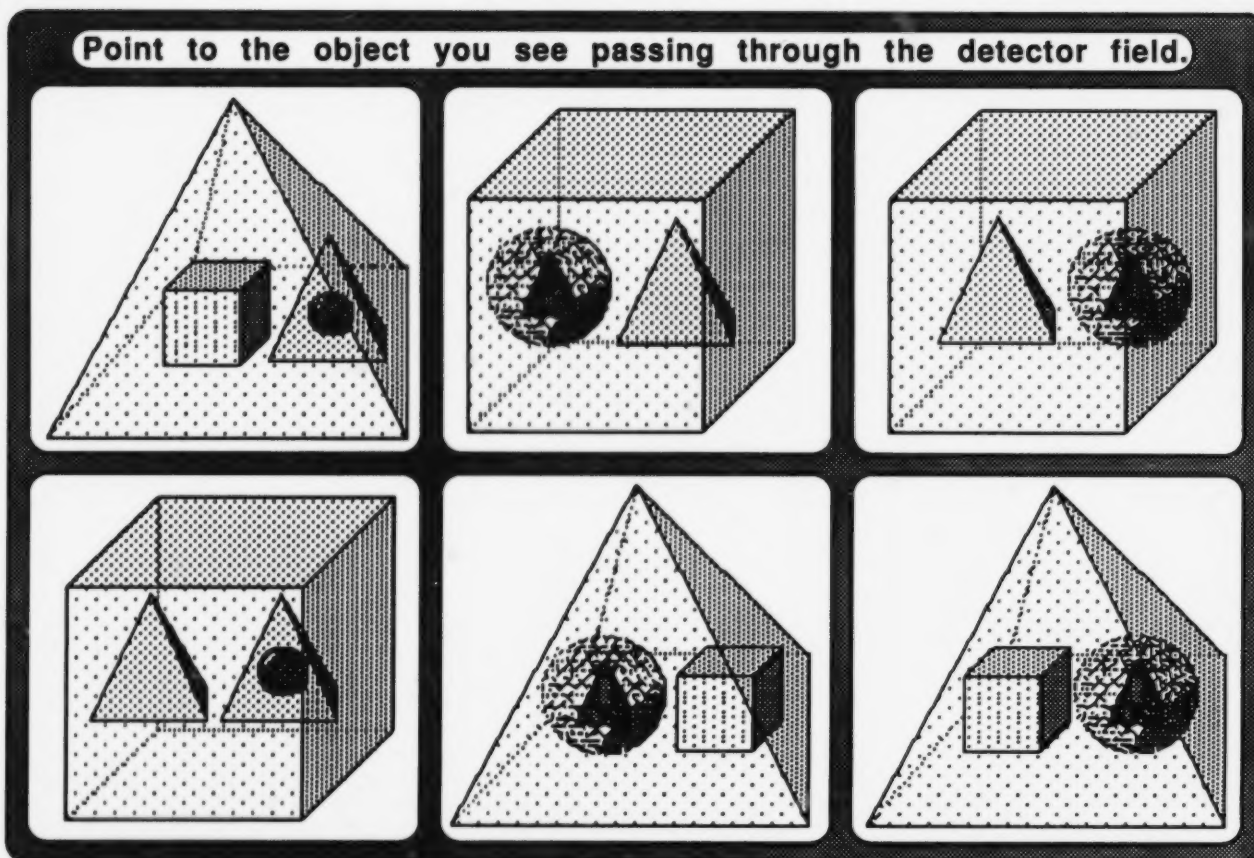


Figure 4
Possible Order and Position Errors



Top row	order error	correct response	position error
Bottom row	order error	order error	order error

Table 1.
Mean Error Types X Object Complexity X Sex

	Error Types							
	Correct		Shape		Order		Position	
	M	F	M	F	M	F	M	F
O-O	5.80	5.81	.10	.09	.10	.09	.00	.00
O-O/O	5.70	5.77	.00	.03	.00	.03	.30	.16
O-O-O	5.60	5.67	.00	.00	.40	.19	.00	.12
O-O/O-O	4.80	5.00	.00	.00	.30	.29	.90	.70
O-C/D	1.30	1.19	4.10	4.30	.60	.42	.00	.00
Totals X Sex	4.64	4.69	.84	.88	.28	.20	.24	.20
Totals All	4.67		.86		.24		.22	

Level 1 (O-O) ---- A medium sized solid embedded in the center of a larger solid.

Level 2 (O-O/O) ---Two adjacent medium sized solids both embedded inside a larger solid.

Level 3 (O-O-O) ---A small solid embedded in the center of a medium sized solid, which are both embedded in a larger solid.

Level 4 (O-O/O-O) -A small solid embedded in a medium solid which is adjacent to another medium solid, all of which are embedded inside a larger solid.

Level 5 (O-C/D)----Cylinders and diamond solids embedded inside of a larger rectangular solid.